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AN ECOLOGICAL SURVEY OF A SANDY BEACH

by

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ABSTRACT

An ecological survey of a sandy beach was made to determine relationships between population densities and sand grain size distributions, season and height above the tidal datum plane (MLLW). Fifteen species of invertebrates in four phyla were collected. Four zones relative to tidal datum and two major habitats - protected outer coast sandy beach and outer coast sandy beach - were defined. *Nephtys caecoides*, *Nephtys californiensis* and *Archaeomysis maculata* showed distinctive distribution patterns relative to mean grain size which require further investigation.

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I. INTRODUCTION

A. NATURE OF THE STUDY

Previous ecological studies of sandy beaches have been either large scale investigations of faunal assemblages and their habitats - for example, intertidal animals of the Pacific Coast of North America [Ricketts and Calvin, 1968] - or investigations into the factors affecting the distribution of one or a few species [Cubit, 1969; Kenny, 1969]. This study attempts to combine features of both approaches by studying a small area and getting quantitative information about the environment and the infauna. The approach was suggested by studies of the distribution of two species of the polychaetous annelid *Nephtys* in the British Isles [Clark and Haderlie, 1960] and of two different species of *Nephtys* along the California coast [Clark and Haderlie, 1962].

The object of this study was to determine the population densities of invertebrate species inhabiting a sandy beach and to relate these densities to such environmental factors as sand grain size distribution, season and position relative to tidal datum (MLLW). To accomplish this, transects were made perpendicular to the water line from lower low water to high water at thirteen stations on a sandy beach at the southern end of Monterey Bay, California, during the months of June, July, October, November and December 1969. Sand samples were taken at these sites in order to correlate grain size and population densities. The data collected included population densities of fifteen invertebrate species, their vertical locations relative to tidal datum, season and measurements of sand grain size.

B. AREA STUDIED

The area studied was a 2.75 mile section of beach (Figure 1) extending from just east of Monterey Municipal Wharf Number 2 (Station A) to the foot of Tioga Avenue in Sand City (Station K). Three areas along the beach are discernible. The first (Stations A, B and E) has a broad flat profile with fine, muddy sand; the second (Stations C, D, F, L, M and H in summer) has a flat to gently sloping profile with fine to medium, clean sands while the third (Stations I, J, G, K and H in winter) has a rather short steep profile with medium (and some coarse), clean sands. The first two areas corresponded to a protected outer coast sandy beach and the third to an outer coast sandy beach as defined by Ricketts and Calvin [1968]. The areas classified as protected outer coast sandy beaches lie in the lee of the Monterey Peninsula and are thus sheltered from all but the most severe winter storms. The remaining stations (I through K) are open to the prevailing sea and swell the year round although some protection is afforded by offshore kelp beds.

The entire area is characterized by a cool, uniform climate and by small annual variations in sea surface temperature and salinity. Thus the primary factors affecting the fauna are wave shock, tidal exposure and type of bottom [Ricketts and Calvin, 1968].

Tides in the bay are of the mixed type having a diurnal range of 5.3 feet and a mean range of 3.5 feet. In summer lower low water, the reference level for this study, occurs from midnight to midmorning, while in winter it occurs from mid-afternoon to late night.

The degree of wave shock in summer is generally small. Heavy surf during this period is associated with distant North Pacific storms. In winter the amount of wave shock increases both as a result of distant

storms and local weather. During this study, the weather was quite uniform over the entire collecting period. Collections were completed prior to the start of the winter rainy season and the period of the most intense storms.

II. METHODS

A. BIOLOGICAL

At each station a transect line was established perpendicular to the shore and ran from lower low water to high water. Along each transect one to nine holes were dug, the average number being five or six. These holes were randomly spaced and each consisted of an excavation one half meter square and approximately 25 cm deep. This gave a sample volume of about 62.5 liters. The sand dug out was passed through a sieve made of standard aluminum window screen with a mesh size of about 1.0 mm. The animals so collected were counted and identified in the field if possible. In general only the annelids, especially Nephtys spp., had to be taken to the laboratory for positive identification. This technique is believed adequate to sample the fauna, as Johnson [1967] indicated that 80 percent of 20,000 individuals studied on a sand flat were found in the upper 15 centimeters.

A total of thirteen stations were studied (Figure 1). Two (A, I) were visited only once during the summer while four (L, M, J and K) were visited only during the winter. The remaining seven were visited in both summer and winter. Summer stations were studied in June and July while winter stations were studied in October, November and the first week of December. The transect at each station was studied only at the time of lower low water in order to cover as wide an expanse of beach as possible.

Station locations were chosen initially to cover the areas where the beach character, indicated by sediment parameters [Dorman, 1968], underwent

some change. Station A was established essentially to test techniques. There was a considerable amount of debris on the beach from the discharge line of a dredge working within the harbor, so data from this station were not used in the study. Stations B, E, C, D, F and G were those originally chosen. Subsequent stations were established where there seemed to be marked variations in either the fauna or the appearance of the beach. The extent to which this procedure introduced bias into the results is not known.

B. SEDIMENTS

Sand samples were taken at most excavations along each transect line for use in particle size analysis. At those stations where the transect comprised only one or two excavations, sand samples were taken at the water's edge, at the high water line and at some intermediate location. Samples were taken at the same depth as most of the animals, about 10 to 15 cm. Samples from the surface and from 15 cm below the surface (Samples B6 and B7) were taken at the high water level at Station B. In this case Sample B6 appeared to be fine, well sorted sand, while B7 appeared to be less well sorted and to contain numerous large shell fragments. Analysis showed no significant differences in the sediment parameters.

Grain size analysis was performed by first baking the samples for a minimum of 24 hours at 135F, and then by agitating through a series of sieves with phi values of -1, 0, 0.5, 1, 2, 3, and 3.5 (phi = $-\log_2 d$, where d is grain diameter in millimeters). The samples were disaggregated by hand and resieved as necessary No mineralogical analyses were made.

Statistical analyses of the sediments were made using computer programs written by Dorman [1968]. Weights of each grain size fraction

read to $\pm$ 0.0001 grams on a Mettler precision balance were used as input data for the program, and the output appeared as cumulative weight distribution (frequency) graphs drawn by a CalComp plotter. The required percentile weight values were read from a hand smoothed cumulative frequency graph and used to compute Inman parameters [Inman, 1952] again using Dorman's program. All five Inman parameters were computed although only mean phi, phi deviation and first phi skewness were used directly in this study.

III. RESULTS

A. GENERAL

A total of fifteen species representing four phyla were collected (see Appendix B). One phylum (Nemertea) was represented by a single small ribbon worm, Carinoma mutabilis, taken at Station E in July. The phylum Mollusca was represented by Tivela stultorum, the Pismo clam, and the sand dwelling snail or olive shell, Olivella biplicata. Crustaceans (phylum Arthropoda) were by far the most numerous and included two anomuran crabs, Blepharipoda occidentalis and the familiar sand crab Emerita analoga; a mysid shrimp, Archaeomysis maculata; the isopod or pill-bug Cirolana harfordi; and two amphipods, Metopa sp. and the familiar beach hoppers Orchestoidea spp. The remaining species were all polychaetous annelids. These were two species of Nephtys; the bloodworm Euzonus mucronata; a single lugworm Arenicola cristata; six individuals of a single unidentified species of the family Spionidae; and five individuals of the family Orbinidae (either Scolopos sp. or Haploscolopos sp.).

Two essentially terrestrial Arthropod groups, the beetles (Coleoptera) and flies (Diptera) have been reported in the literature but were not collected in this study. They occur at the high water level and are most common around seaweed tossed up by storms.

1. Sedimentary Relations

Population densities for most species were plotted against mean phi (Figures 2, 3 and 4). In all cases the population densities were taken as number of a given species per .25 m^2 surface area. Animals were

found in sands throughout the entire range of mean phi (0.34 to 2.38) although the majority were found in sands with mean phi greater than 1.30. No interpolation of phi parameters between locations was done and population densities were plotted only where sediment data were available.

Three species, Nephtys caecoides, N. californiensis and Archaeomysis maculata, which showed distinct patterns relative to mean phi were also plotted against median phi (Figure 5) to determine whether mean phi or median phi was the better measure, in biological terms, of the central tendency of the sand grain size distribution. Qualitatively it appeared that neither was superior, so in this case mean phi was arbitrarily chosen.

Six species, Cirolana harfordi, Emerita analoga and Euzonus mucronata, representing population densities greater than 10 per 0.25 m^2, and Nephtys caecoides, N. californiensis and Archaeomysis maculata, representing population densities less than 10 per 0.25 m^2, were plotted against phi deviation (Figure 6). This parameter is a measure of sorting or the tendency for the majority of the grains to be the same size. Values of phi deviation from 0.0 to 0.5 indicate good sorting and from 0.5 to 1.0 indicate fair sorting. In this case the range of phi deviation was small (0.40 to 0.78) and no significant patterns relative to populations were found. This result was not surprising when compared with the lack of pattern shown in the plot of phi deviation against mean phi (Figure 7).

Five species, Emerita analoga, Euzonus mucronata, Nephtys caecoides, N. californiensis and Archaeomysis maculata were plotted against first phi skewness (Figure 8), a measure of the tendency of the

central portion of the sediment size distribution toward either fine (values greater than zero) or coarse (values less than zero) grains. *Nephtys californiensis* and *Euzonus mucronata* were found only in sands with positive skewness; however, only six samples out of 42 showed negative skewness and these were evenly divided between coarse to medium sands and fine sands so that no significance could be attached to the pattern.

The data were also examined to see if some relation existed between a particular range of mean phi and zero population densities. No such relation was found which suggested that distribution of animals within a suitable habitat was random.

2. Seaonsal Patterns

Seasonal Patterns are depicted in Tables I and II. The absence of *Euzonus mucronata* during the summer was the most striking variation and is discussed further in a later paragraph.

Both the Spionids and the Orbinids were found only in winter. Their normal habitat is among the holdfasts of the littoral kelp beds (*Nereocystis luetkeana*) common along the entire area studied. In winter great numbers of these plants are tossed on the beach along with the fauna characteristic of the beds so the presence of these two families could be explained as being the result of winter storms.

The two most abundant species taken, *Emerita analoga* and *Cirolana harfordi*, showed no seasonal variations, nor did any of the other species except *Nephtys caecoides*, *N. californiensis* and *Archaeomysis maculata* show patterns which could be interpreted as seasonal.

Nephtys caecoides was more abundant in summer than in winter while the reverse was true for *Nephtys californiensis*. This is difficult

to explain since one might reasonably expect fewer animals of both species because of the increased surf activity in the winter. Archaeomysis maculata was also more abundant in winter than in summer but no reason for this difference could be found.

3. Distributions Across the Beach

Table III shows the positions of each species relative to the tidal datum plane. The data for both summer and winter were combined since no seasonal patterns in vertical positions were found. Four distinct zones based on either a small total population or on a dominant species were noted. The problems of zonation on a sandy beach have not been discussed in the literature in great detail. The excellent review of zonation on rocky shores in Ricketts and Calvin [1968] was the work of Hedgpeth but he made no comment whatever on sandy beaches.

Zone 1 (6.0 - 2.5 feet) extended from high water to just below mean tide level (2.8 feet) and corresponded to zones 1 and 2 of Ricketts and Calvin [1968]. This zone was dominated by Cirolana harfordi and Orchestoidea spp. A few Emerita analoga were found principally in the lower limits of the zone.

Zone 2 (2.5 - 0.5 feet) was dominated by Emerita analoga and Euzonus mucronata. Euzonus mucronata were actually found in a smaller band from 1.5 to 0.7 feet within the zone. A large number of Cirolana harfordi were taken in a narrow band from 0.7 to 0.5 feet.

Zone 3 was distinguished by a lack of animals although a moderate number of Emerita analoga were taken in this zone. Zone 2 and zone 3 together corresponded to zone 3 of Ricketts and Calvin [1968].

Zone 4 covered the area below tidal datum and included the widest variety of animals. Only Orchestoidea spp. and Orbinids were not found

in this zone which corresponded to zone 4 of Ricketts and Calvin [1968]. Zonal correspondence was based solely on height relative to tidal datum.

B. DETAILED DISCUSSIONS OF SPECIFIC SPECIES

More detailed discussions of the distribution of Nephtys, Archaeomysis and Euzonus are presented in this section.

1. Nephtys caecoides and N. californiensis

Nephtys caecoides and N. californiensis were found to be separated spatially by the character of the substrate. N. caecoides was found at nearly all tide levels in both clean and muddy sands with mean phi greater than 1.75. N. californiensis was generally found in clean sands with mean phi from 1.31 to 1.82, although two individuals were taken at Station B in muddy sand with a mean phi of 2.32. The separation of the species was thus found to be less complete than that reported by Clark and Haderlie [1962]. Figure 9 shows graphically the small differences in substrates found to be characteristically inhabited by the two species. In this graph the plot for Station B was excluded from the sites populated by N. californiensis. If it had been included the plots would have overlapped completely.

Ricketts and Calvin [1968] reported N. californiensis to be common in the beds of the bloodworm Euzonus mucronata. This would explain its location at Station B since this station was found to be suitable in terms of grain size for Euzonus. However, only one Euzonus was taken at Station B in the summertime so the presence of two individuals of N. californiensis is regarded as anomalous. Moreover, examination of Tables II and III shows that the maximum population densities of Nephtys and Euzonus were not coincident.

N. caecoides was taken more often in summer (20 individuals) than in winter (6 individuals) while the situation was reversed for N. californiensis (6 individuals in summer, 15 individuals in winter). This may have been the result of sampling more coarse grained stations in the winter, although the two stations (D, F) with the largest numbers were visited in both seasons.

No individuals of either species were taken at Station G in summertime or at Stations B, H, J, and G in winter. Station G was washed by heavy surf in both seasons, and Stations H and J were washed by heavy surf in the winter and thus were unsuitable for either species. These stations were populated almost exclusively by Emerita. Failure to find any animals at a suitable season was probably due to the random distribution of a small population and the fact that no special effort was made to find Nephtys at every station.

2. Archaeomysis maculata

This shrimp was found in medium to coarse sand at only two stations in each season. (I and G in summer, L and M in winter). All but one were found in the wet sand near the water's edge. More were found in winter than in summer, but in each case the shrimp were taken at about the southern extent of maximum surf activity. This suggests the possibility that the animals migrate in order to stay in relatively coarse sand but outside the heaviest surf activity.

3. Euzonus mucronata

This species has been found in large numbers all along the beach in the past [Haderlie, personal communication]. During the course of this study only one individual was taken (at Station B) in the summertime. In winter large numbers (91 percent of the total) were taken in

a narrow band just above tidal datum (Table III) at three stations. Fishermen encountered on the beach during the course of the study confirmed that a previously abundant species favored as bait was scarce during 1969. Those taken in winter were invariably in the top 5.0 cm of sand and presented the appearance of a dense red band about 2.5 cm thick when viewed in a vertical section. All were taken in medium to fine sand with mean phi greater than 1.8.

IV. DISCUSSION AND CONCLUSIONS

The intertidal fauna of this area is limited in both variety and numbers. Eleven of the fifteen species (1453 individuals) have been characteristically found in this habitat in the past. Of the other four, Arenicola cristata has been more commonly found in mudflats or subtidally but occasionally higher up on the beach. This individual appears to have been one of the occasional variety. The remaining three (Carinoma mutabilis, Orbinids and Spionids) have not been reported from this habitat.

Emerita analoga was taken at all stations, except A, and at all distances from the water. It was common near the water and in a wide band just above tidal datum level. Cirolana harfordi was most common at high water but a large number were also taken below mean tide level. Cirolana was less numerous and less widely distributed than Emerita, but still showed no preference for a particular substrate texture. Orchestoidea spp. were found at the high water level almost exclusively but were not counted. Of the large populations - i.e., those with a population density greater than ten at any given site - only Euzonus mucronata exhibited a preference for a particular sediment texture. It was found in sands with mean phi greater than 1.8. Its abundance only in the winter collecting period could not be explained. These four species were represented by a total of 1362 individuals including the 28 Orchestoidea spp. actually counted. Two habitats can then be delineated: a fine sand region with mean phi greater than 1.8 where Euzonus could be found and a coarser region with no Euzonus. The first included the stations between A and F or a little more than a third of the beach.

All of the remaining six species had small population densities. The amphipod Metopa sp. was found at all water levels and in all but the finest sand. Tivela stultorum, the Pismo clam, was taken in fine sand at the most sheltered end of the beach rather than in areas with heavy surf where it would have been expected [Ricketts and Calvin, 1968, p. 221]. Olivella biplicata was also found in small numbers (total seven) in sand with mean phi from 1.49 to 1.83.

Nephtys and Archaeomysis were found in distinct regions. N. caecoides was taken from medium to fine, generally muddy sand, while N. californiensis was taken from clean medium sand which was coarser than that inhabited by N. caecoides. The separation of these species was not as complete as indicated by Clark and Haderlie [1962]. Archaeomysis was found in medium to coarse sand just south of the heaviest surf.

Three overlapping regions along the beach were defined. One characterized by Euzonus and N. caecoides had a gently sloping broad beach with generally light surf. A second had cleaner coarser sand than the first and was characterized by N. californiensis. Its northern limit seemed to coincide with the appearance of Archaeomysis. These two represented a protected outer coast sandy beach but differed from each other in amount of mud and degree of wave shock. The third region, the northern limit of the area studied, had heavy surf year round and a population made up almost exclusively of Emerita. The beaches in this region were steep and short, typical of the open outer coast sandy beach. The limits of the regions overlapped to some extent, particularly between the first two, and were found at different locations seasonally. In particular the boundary between regions two and three was marked by the position of Archaeomysis (I and G in summer, L and M in winter). It should be

remembered, however, that boundaries in the sense used here are often transition zones several hundred feet wide.

V. RECOMMENDATIONS

Further study of this kind is recommended in order to discover the true seasonal patterns in the populations and to more fully understand the distribution of *Nephtys*. In order to accomplish these tasks two types of approach are suggested.

Two or three permanent stations, one in each area outlined above, are recommended to determine seasonal patterns. These stations should be studied at least monthly (more often, if possible) over the course of a full year. Studies should be made at all tide stages. Periodic sampling should be done at intermediate stations to keep track of the overall character of the beach. Beside sediment size parameters, data on temperature, interstitial salinity and porosity should be taken to determine if these factors are influential. Because of the magnitude of this effort, particularly the physical effort in making an adequate study, at least two people should be involved. The effort might be split into a biological problem and a sedimentary problem.

Evaluation of the distribution of *Nephtys* would require several stations over a short section of beach. The area from Stations A to D would be ideal in this regard. This study could be completed in six months. Transects should be made across the entire beach and continued into the water at least to a depth that could be sampled without using a boat. Any areas where both *Nephtys caecoides* and *N. californiensis* were found should be studied in detail.

A reliable means to accurately collect all the invertebrate inhabitants in a given volume of sand would give better data. The principle

difficulty is that a large volume must be sampled so as not to miss members of sparse populations, and there is no way of knowing how many animals escape by burrowing further into the sand. This could be done by sampling the entire volume at once, or by sampling several small volumes scattered randomly over an area four meters by one meter with the long dimension oriented parallel to the water line. These dimensions are arbitrary and a statistical analysis of the optimum sampling technique would be most useful.

APPENDIX A

STATION DATA

Numbers in parentheses after sediment sample number give height above datum - MLLW.

A 250 feet east of Monterey Municipal Wharf No. 5. Beach faces NNE, flat broad beach with fine muddy sand.

Sediment sample: A1 (-1.4) - 4 June

B 300 feet east of Monterey Municipal Wharf No. 2. Beach faces NNE, flat broad beach with fine muddy sand.

Sediment samples: B2 (-1.9), B3 (-1.7), B4 (-1.2), B5 (-0.6),
B6 (5.5) surface sample, B7 (5.5) subsurface sample - 1 July
B12 (-0.4), B13 (1.1), B11 (4.5) - 8 November

E Center of Monterey State Beach, 600 feet west of Park Avenue. Beach faces N, flat broad clean fine sand.

Sediment sample: E12 (-1.1) - 3 July

C East end of Monterey State Beach, 100 feet west of Park Avenue. Beach faces N, flat broad clean fine sand.

Sediment samples: C8 (-1.6), C9 (5.0) - 2 July
C14 (-0.7), C15 (4.8) - 26 October

D On western U. S. Navy property line. Beach faces NNW, gentle slope, clean medium sand.

Sediment samples: D10 (-0.3), D11 (4.8) - 6 June

F Foot of Beach Way on Del Monte Beach. Beach faces NNW, gentle slope, clean medium sand.

Sediment samples: F13 (-1.5), F14 (2.5), F15 (5.5) - 27 July
F10 (-0.9), F3 (0.2), F2 (4.5) - 9 November

L 500 feet northeast of Surf on Del Monte Beach. Beach faces NNW, gentle slope, clean medium sand.

M 1300 feet southwest of Holiday Inn. Beach faces NW, moderate slope, clean medium sand.

Sediment samples: M18 (-1.0), M15 (-0.3), M21 (4.5) - 7 December

H 700 feet southwest of Holiday Inn. Beach faces NW, moderate slope (summer) to steep slope (winter), clean medium sand.

Sediment samples: H19 (-1.4), H20 (0.6) - 30 July

I 100 feet northeast of Holiday Inn. Beach faces NW, steep slope, clean medium sand, some coarse sand.

Sediment samples: I21 (-0.9), I22 (1.3), I23 (2.5), I24 (5.5) - 31 July

J 200 feet southwest of Seaside Sewage Plant outfall. Beach faces NW, steep slope. Clean medium sand.

Sediment samples: J16 (-0.3), J17 (0.7), J18 (5.5) - 24 October

G 50 feet southwest of Seaside Sewage Plant outfall. Beach faces NW, steep slope, clean medium to coarse sand.

Sediment samples: G16 (-1.7), G17 (1.5), G18 (5.0) - 29 July
G13 (-0.8), G14 (1.3), G3 (4.5) - 22 November

K 150 feet southwest of Tioga Avenue, Sand City. Beach faces NW, steep slope, clean medium sand.

Sediment samples: K19 (-0.6), K20 (1.2), K21 (5.0) - 25 October

APPENDIX B

SYSTEMATIC INDEX

Phylum NEMERTEA

Carinoma mutabilis Griffin

Phylum ANNELIDA
Class Polychaeta

Family Nephtyidae
Nephtys caecoides Hartman
Nephtys californiensis Hartman

Family Ophelidae
Euzonus mucronata (Treadwell)

Family Arenicolidae
Arenicola cristata Stimpson

Family Orbinidae
Haploscopopos sp. or *Scolopos* sp.

Family Spionidae
1 unidentified species

Phylum ARTHROPODA
Class Crustacea

Order Mysidacea
Archaeomysis maculata (Holmes)

Order Isopoda
Cirolana harfordi (Lockington)

Order Amphipoda
Metopa sp.
Orchestoidea spp.

Order Decapoda
Blepharipoda occidentalis Randal
Emerita analoga (Stimpson)

Phylum MOLLUSCA
Class Gastropoda

Order Neogastropoda
Olivella biplicata (Sowerby)

Class Pelecypoda

Order Eulamellibranchia
Tivela stultorum (Mawe)

TABLE I

Total population densities at each station - summer data. -- indicates station not occupied during this season. Stations listed in order from south to north.

SPECIES, GENUS, OR FAMILY	B	E	C	D	F	L	M	H	I	J	G	K
Carinoma mutabilis		1				--	--			--		--
Nephtys caecoides	1	3	9	5		--	--			--		--
Nephtys californiensis	1				1	--	--	3	1	--		--
Euzonus mucronata	1					--	--			--		--
Arenicola cristata		1				--	--			--		--
Orbinidae						--	--			--		--
Spionidae						--	--			--		--
Archaeomysis maculata						--	--		1	--	2	--
Cirolana harfordi	2	3	3			--	--	86	21	--		--
Metopa sp.		3	1	4	1	--	--	4		--		--
Orchestoidea spp.	1	1				--	--	13	2	--		--
Blepharipoda occidentalis			1			--	--			--		--
Emerita analoga	31	33	99	86	5	--	--	24	114	--	156	--
Olivella biplicata				6	1	--	--			--		--
Tivela stultorum	1					--	--			--		--

TABLE II

Total population densities at each station - winter data. -- indicates station not occupied during this season. Stations listed in order from south to north.

SPECIES, GENUS, OR FAMILY	B	E	C	D	F	L	M	H	I	J	G	K
Carinoma mutabilis									--			
Nephtys caecoides		2	4						--			
Nephtys californiensis		1		5	4	1	3		--			1
Euzonus mucronata	45	11			114				--			
Arenicola cristata									--			
Orbinidae				5					--			
Spionidae					6				--			
Archaeomysis maculata						2	7		--			
Cirolana harfordi		131		4	1	1			--	2		
Metopa sp.			3	5	1				--	3		
Orchestoidea spp.		1				x			--			
Blepharipoda occidentalis				1	1				--			
Emerita analoga	11	17	2	30	88	23	37	4	--	83	2	70
Olivella biplicata									--			
Tivela stultorum			1						--			

TABLE III

Population densities vs. height (in feet) above or below tidal datum plane (MLLW).

SPECIES, GENUS, OR FAMILY	Zone One 6.0--2.5	Zone Two 2.5--0.5	Zone Three 0.5--0.0	Zone Four 0.0-- -1.9
Carinoma mutabilis				1
Nephtys caecoides	4	3		17
Nephtys californiensis	1		4	16
Euzonus mucronata	5	156	9	2
Arenicola cristata				1
Orbiniidae				5
Spionidae			6	
Archaeomysis maculata			1	11
Cirolana harfordi	157	87	1	9
Metopa sp.	4	2		18
Orchestoidea spp.	28			
Blepharipoda occidentalis				3
Emerita analoga	59	408	76	384
Olivella biplicata		3	3	1
Tivela stultorum				2

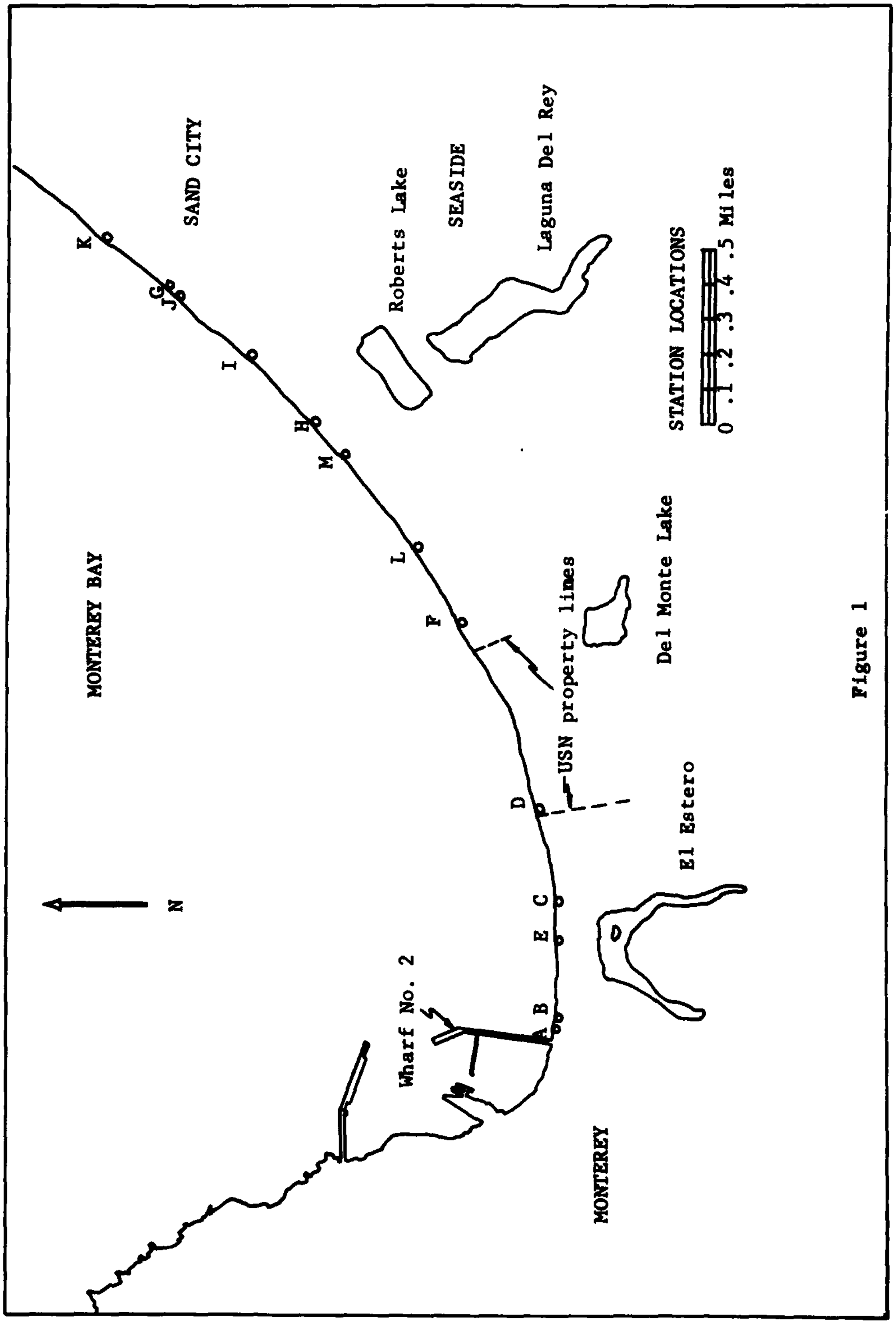
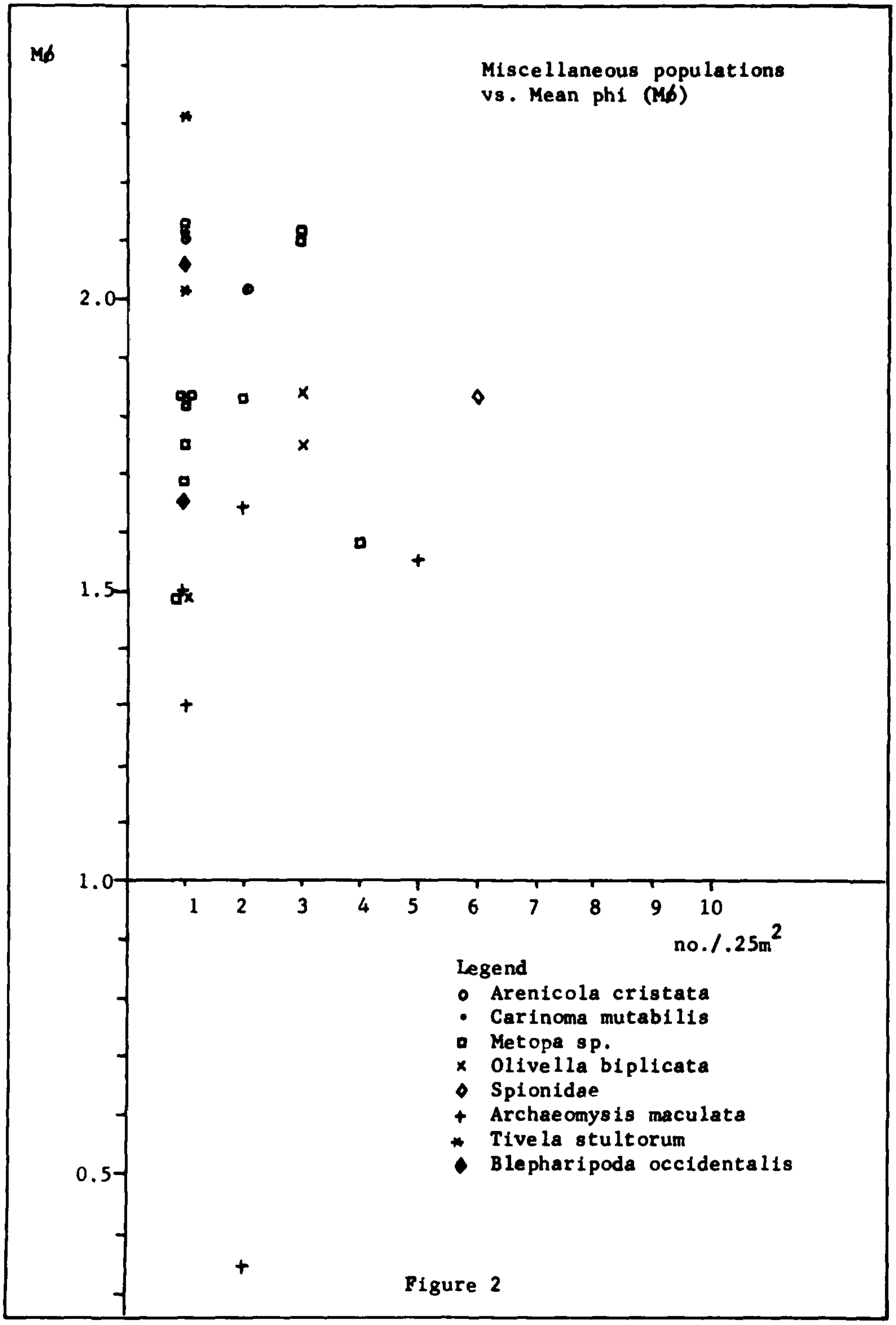
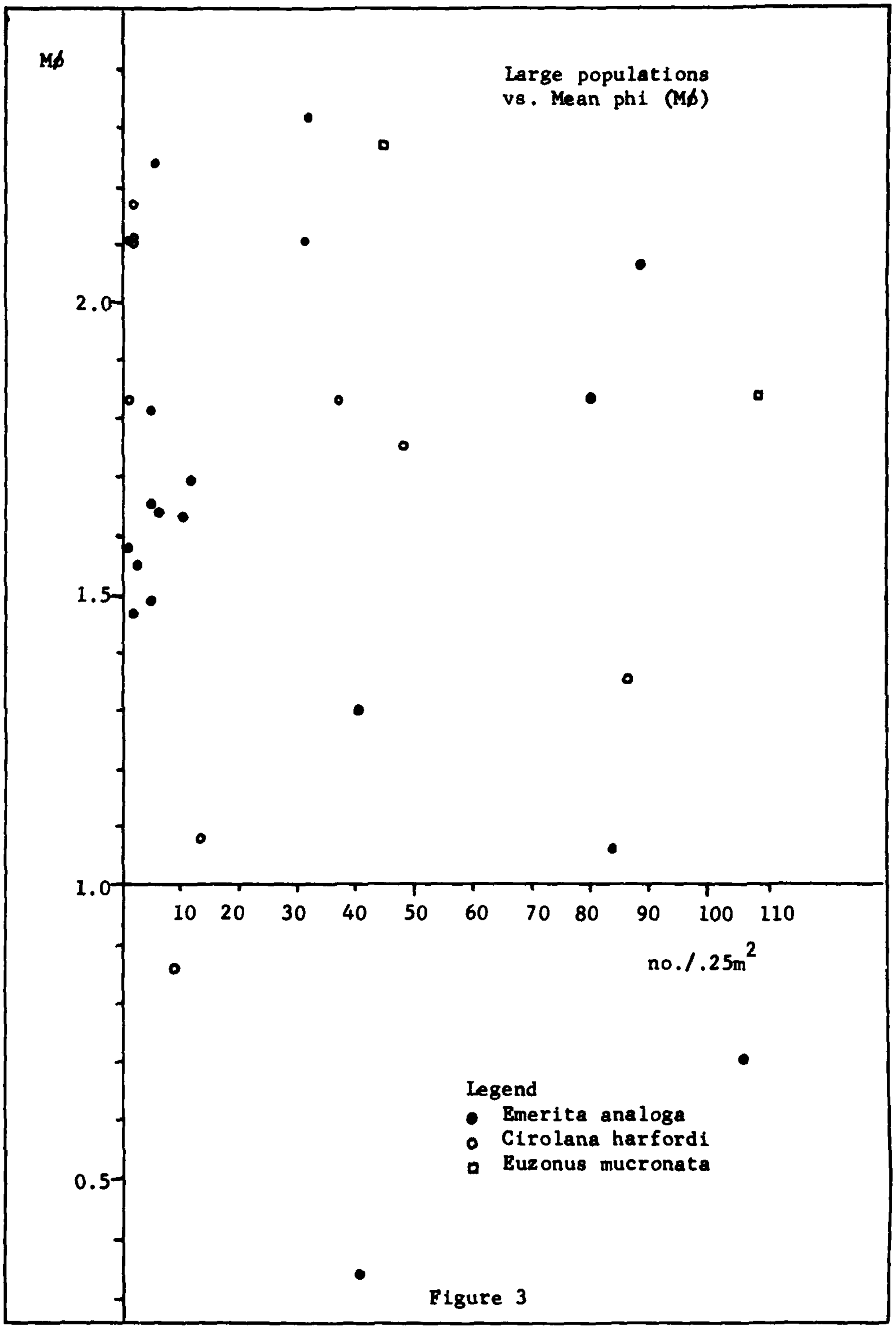

MONTEREY BAY
SAND CITY
Roberts Lake
SEASIDE
Laguna Del Rey
STATION LOCATIONS
0 .1 .2 .3 .4 .5 Miles
Del Monte Lake
USN property lines
El Estero
Wharf No. 2
MONTEREY
N
K
G
J
I
H
M
L
F
D
C
E
B
A

Figure 1



Mϕ
Miscellaneous populations
vs. Mean phi (Mϕ)
2.0
1.5
1.0
0.5
1
2
3
4
5
6
7
8
9
10
no./.25m²
Legend
o Arenicola cristata
• Carinoma mutabilis
□ Metopa sp.
× Olivella biplicata
◊ Spionidae
+ Archaeomysis maculata
✱ Tivela stultorum
♦ Blepharipoda occidentalis

Figure 2


Mϕ
Large populations
vs. Mean phi (Mϕ)
2.0
1.5
1.0
0.5
10 20 30 40 50 60 70 80 90 100 110
no./.25m²
Legend
Emerita analoga
Cirolana harfordi
Euzonus mucronata
Figure 3

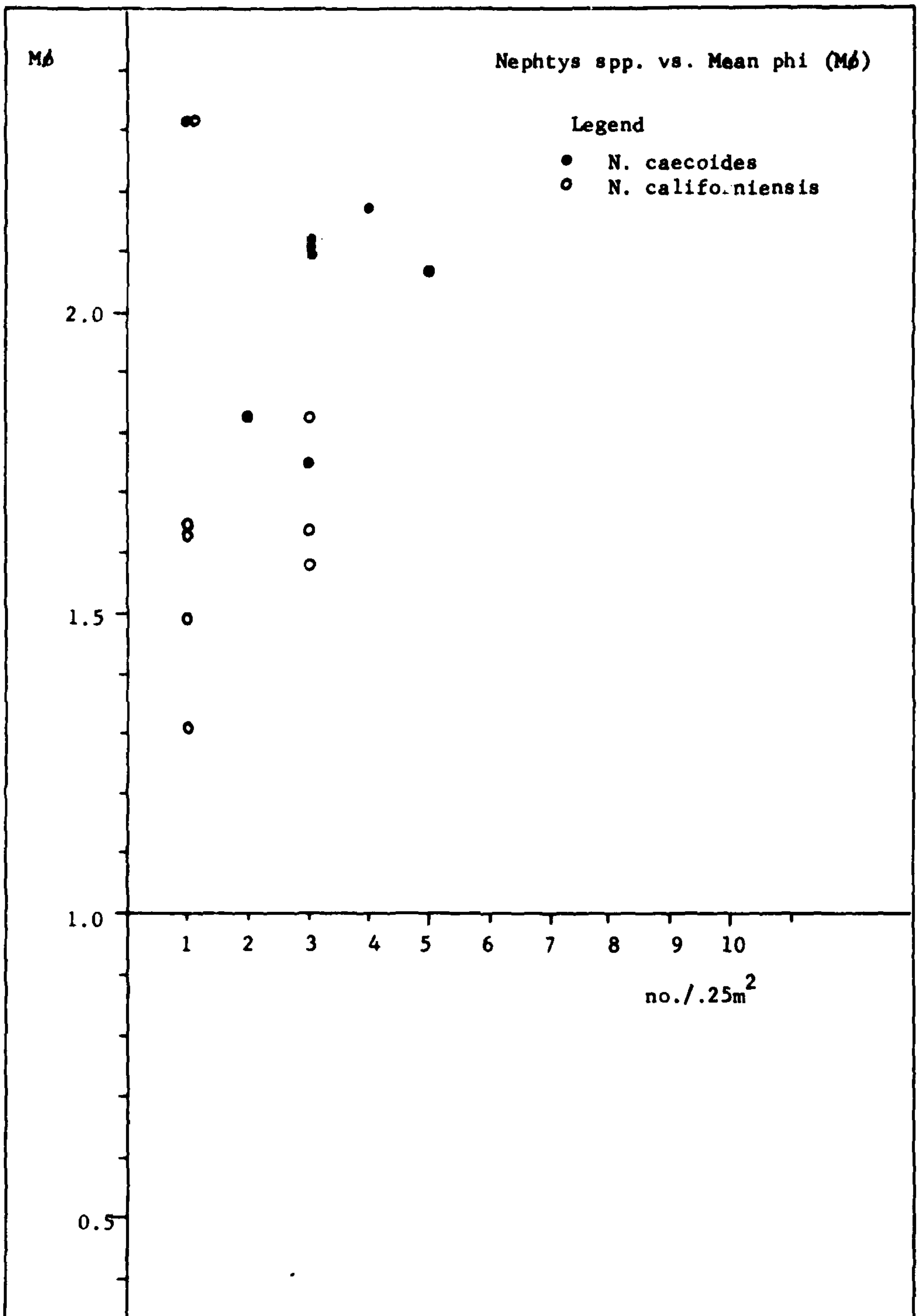

Mϕ
Nephtys spp. vs. Mean phi (Mϕ)
Legend
● N. caecoides
o N. califo.niensis
2.0
1.5
1.0
0.5
1 2 3 4 5 6 7 8 9 10
no./.25m2

Figure 4

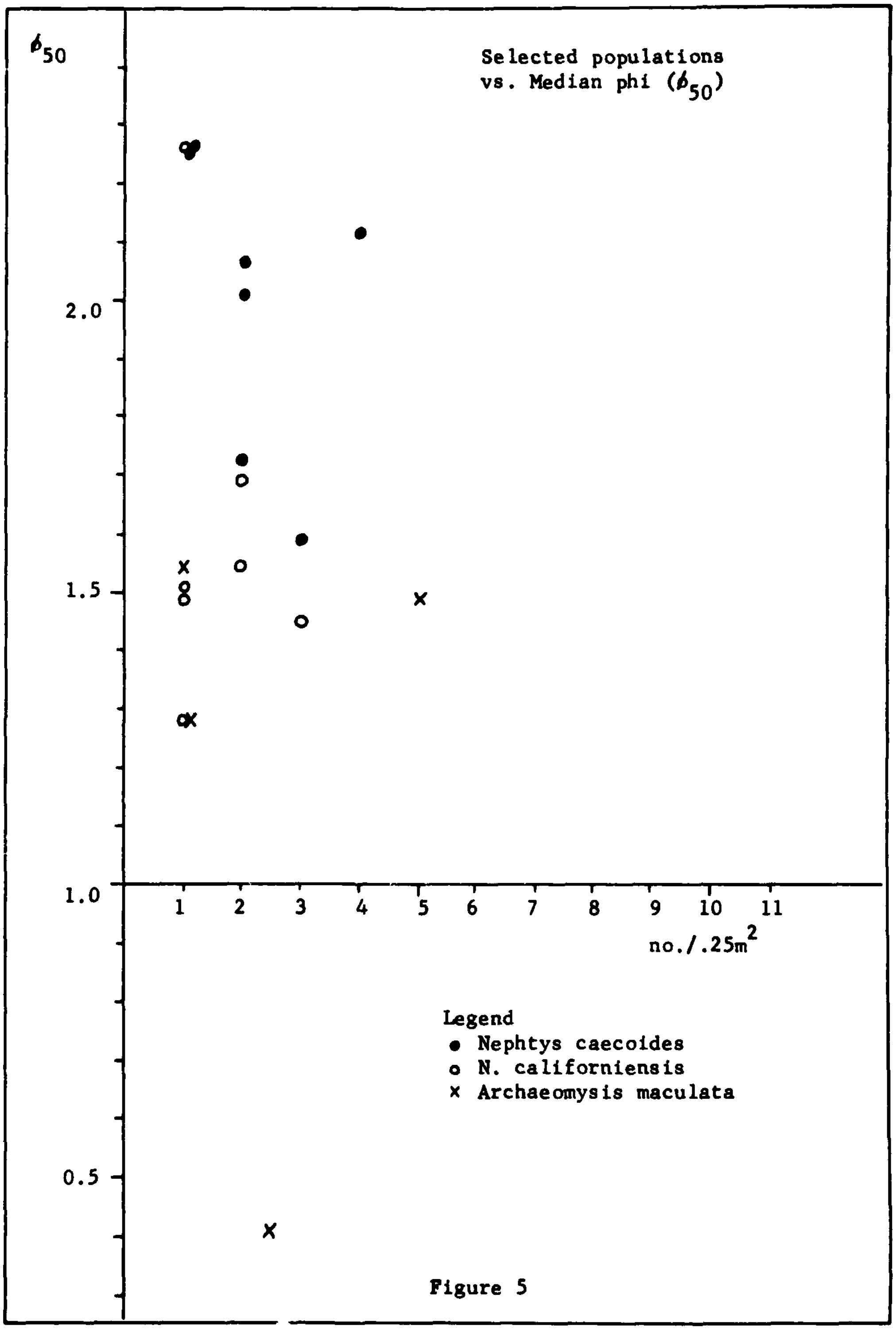

ϕ_{50}
Selected populations
vs. Median phi (ϕ_{50})
2.0
1.5
1.0
0.5
1
2
3
4
5
6
7
8
9
10
11
no./.25m^2
Legend
● Nephtys caecoides
o N. californiensis
× Archaeomysis maculata

Figure 5

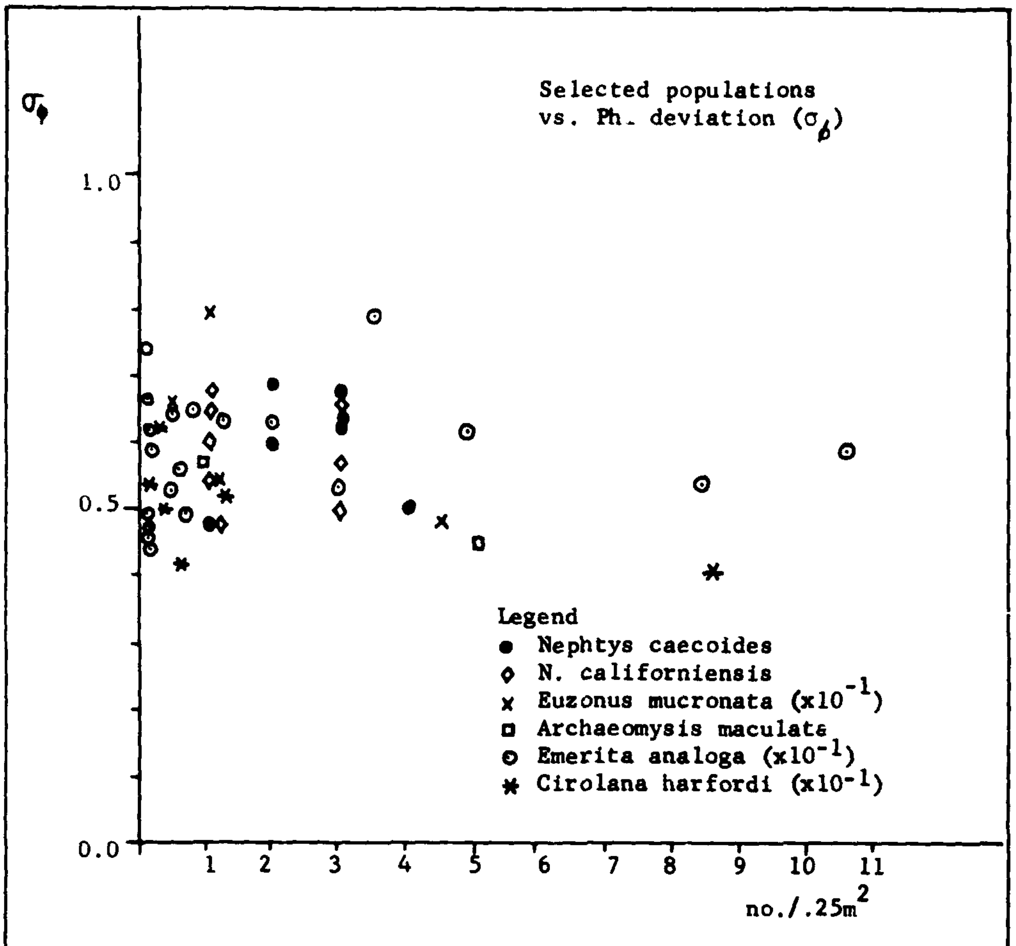
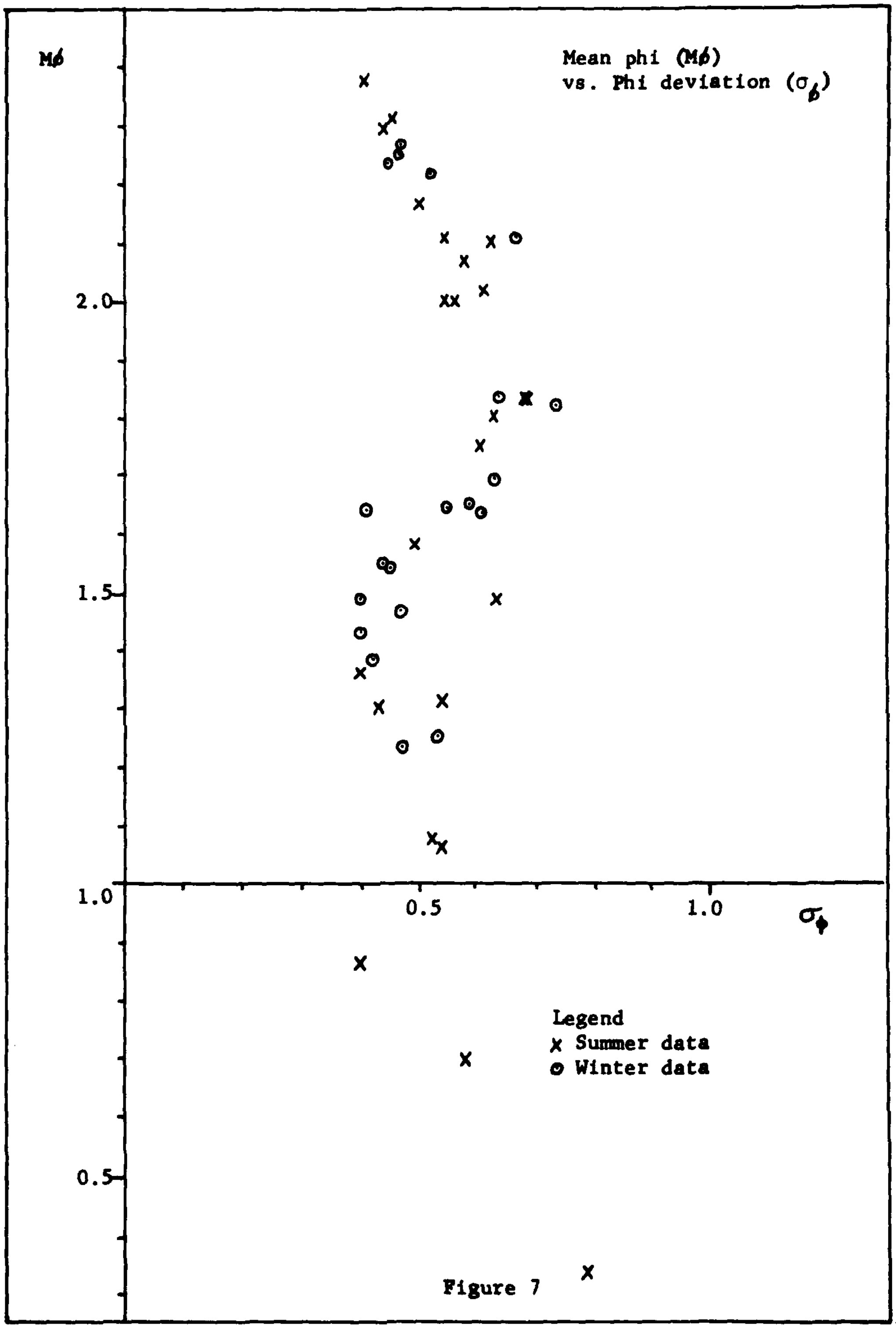
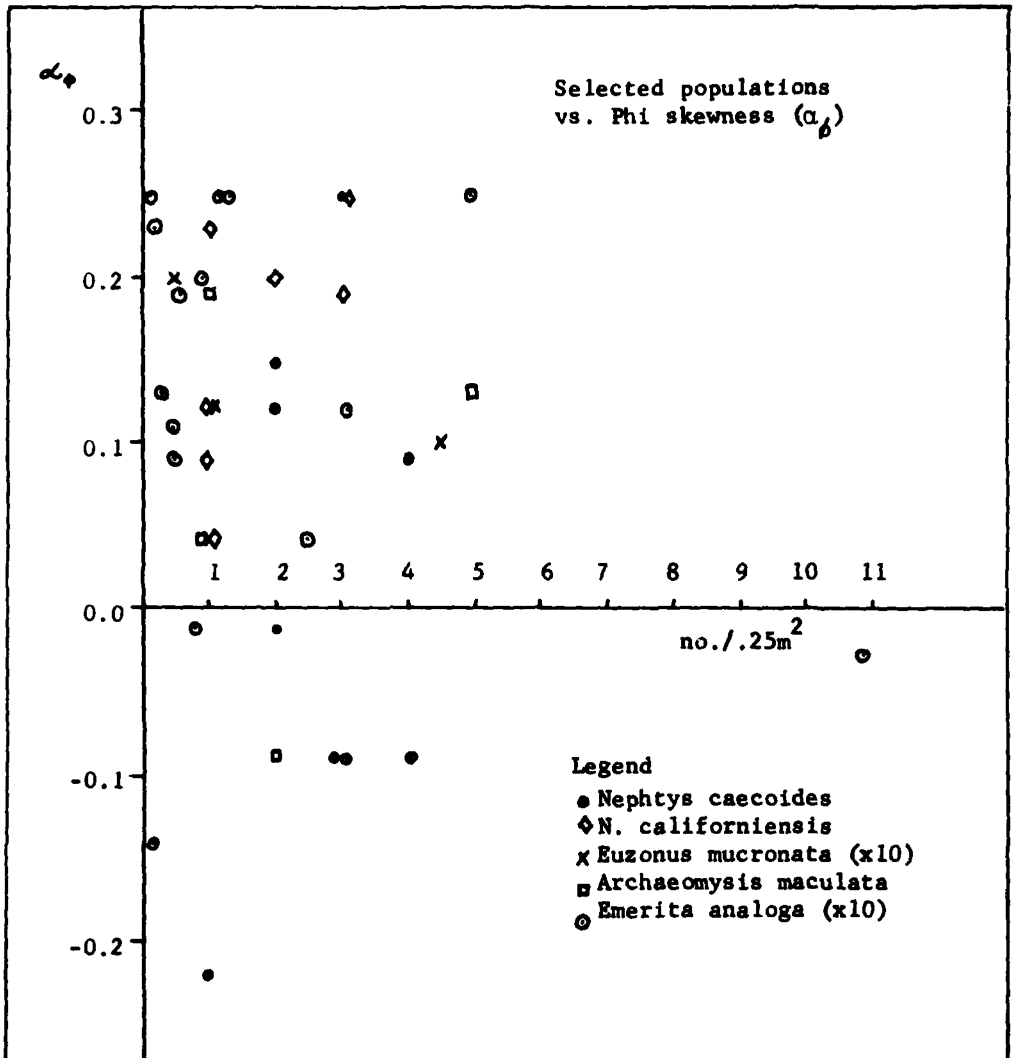

Selected populations
vs. Ph. deviation (σ_ϕ)
σ_ϕ
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
11
no./.25m^2
Legend
Nephtys caecoides
N. californiensis
Euzonus mucronata ($\times 10^{-1}$)
Archaeomysis maculata
Emerita analoga ($\times 10^{-1}$)
Cirolana harfordi ($\times 10^{-1}$)

Figure 6



Mø
Mean phi (Mø)
vs. Phi deviation (σø)
2.0
1.5
1.0
0.5
0.5
1.0
σφ
Legend
x Summer data
o Winter data

Figure 7



Selected populations
vs. Phi skewness (α_φ)
0.3
0.2
0.1
0.0
-0.1
-0.2
1 2 3 4 5 6 7 8 9 10 11
no./.25m²
Legend
Nephtys caecoides
N. californiensis
Euzonus mucronata (x10)
Archaeomysis maculata
Emerita analoga (x10)

Figure 8

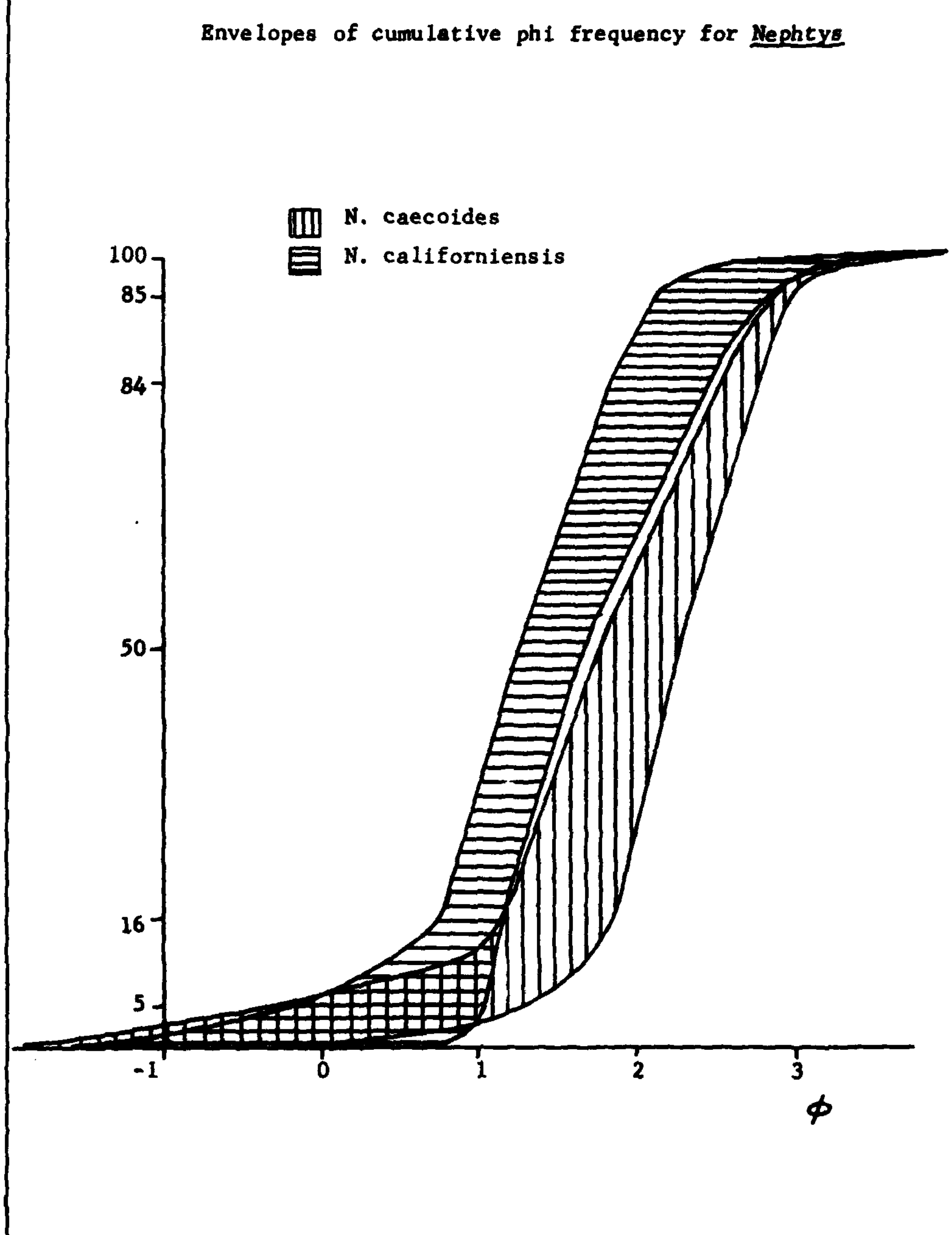

Envelopes of cumulative phi frequency for Nephtys
N. caecoides
N. californiensis
100
85
84
50
16
5
-1
0
1
2
3
ϕ

Figure 9

SAMPLE	PHI-95	PHI-84	PHI-50	PHI-16	PHI-5	MEDIAN PHI	MEAN PHI	PHI DEVIATION	PHI SKEWNESS	2ND PHI SKEWNESS	PHI KURTOSIS
A 1	2.9105	2.6439	2.0116	1.3959	1.1649	2.0116	2.0199	0.6240	0.0133	0.0418	0.3988
B 2	2.9654	2.7859	2.2584	1.8468	1.3292	2.2584	2.3164	0.4695	0.1234	-0.2363	0.7429
B 3	2.9214	2.6529	2.0589	1.5649	1.1649	2.0589	2.1089	0.5440	0.0919	-0.0290	0.6144
B 4	2.8365	2.5735	1.8783	1.4266	1.1811	1.8783	2.0000	0.5734	0.2123	0.2276	0.4434
B 5	2.7563	2.5479	1.8890	1.4620	1.2311	1.8890	2.0049	0.5430	0.2136	0.1929	0.4045
B 6	2.9658	2.8365	2.3364	1.9269	1.4659	2.3364	2.3817	0.4549	0.0995	-0.2651	0.6488
B 7	2.9434	2.7466	2.2584	1.8625	1.3921	2.2584	2.3046	0.4421	0.1044	-0.2051	0.7546
B 12	2.9434	2.6897	2.1910	1.7859	1.4266	2.1910	2.2378	0.4519	0.1035	-0.0132	0.6783
B 13	2.9324	2.7370	2.2176	1.7959	1.3733	2.2176	2.2664	0.4706	0.1035	-0.1376	0.6566
B 11	2.9214	2.7274	2.2379	1.7909	1.3771	2.2379	2.2591	0.4683	0.0454	-0.1893	0.6490
E 12	2.9434	2.7274	2.1584	1.4739	0.9602	2.1584	2.1007	0.6267	-0.0922	-0.3297	0.5822
C 8	2.9324	2.6529	2.0710	1.4779	0.9574	2.0710	2.0654	0.5875	-0.0094	-0.2147	0.6809
C 9	2.8997	2.6620	2.1203	1.6712	1.3076	2.1203	2.1666	0.4954	0.0934	-0.0336	0.6068
C 14	2.9885	2.7760	2.2515	1.4383	-0.4125	2.2515	2.1071	0.6698	-0.2159	-1.4406	1.5425
C 15	2.9885	2.7274	2.1456	1.7131	0.9546	2.1456	2.2202	0.5071	0.1472	-0.3433	1.0053
D 10	2.8468	2.5146	1.7322	1.1520	1.0145	1.7322	1.8333	0.6913	0.1484	0.2914	0.3448
D 11	2.7563	2.3511	1.5951	1.1392	1.0029	1.5951	1.7452	0.6059	0.2477	0.4696	0.4469
F 13	2.6439	2.1329	1.4305	0.8468	-0.1763	1.4305	1.4899	0.6430	0.0923	-0.3060	1.1929
F 14	2.8365	2.5064	1.7370	1.1520	1.0000	1.7370	1.8292	0.6772	0.1362	0.2677	0.3560
F 15	2.8262	2.4344	1.6897	1.1681	1.0350	1.6897	1.8013	0.6331	0.1763	0.3806	0.4145
F 10	2.7274	2.2447	1.5146	1.0589	0.5374	1.5146	1.6518	0.5929	0.2314	0.1987	0.8468
F 3	2.8365	2.4739	1.6943	1.1811	1.0589	1.6943	1.8275	0.6464	0.2061	0.3920	0.3750
F 2	2.3959	2.0589	1.5907	1.2311	1.1234	1.5907	1.6450	0.4139	0.1310	0.4081	0.5372
M 18	2.5735	2.1976	1.5353	1.0862	0.8573	1.5353	1.6419	0.5557	0.1918	0.3240	0.5442
M 15	2.3219	1.9885	1.4941	1.1140	1.0116	1.4941	1.5513	0.4372	0.1307	0.3949	0.4984
M 21	2.0954	1.8943	1.4344	1.0923	0.9828	1.4344	1.4933	0.4010	0.1470	0.2611	0.3873
H 19	2.4659	2.0710	1.4540	1.0831	0.7179	1.4540	1.5771	0.4939	0.2491	0.2791	0.7696
H 20	1.9434	1.7612	1.3219	0.9546	0.6781	1.3219	1.3579	0.4033	0.0891	-0.0277	0.5686
I 21	2.1456	1.8314	1.2828	0.7809	0.3111	1.2828	1.3061	0.5252	0.0444	-0.1036	0.7464
I 22	1.8890	1.5995	0.9743	0.5187	0.2076	0.9743	1.0591	0.5404	0.1570	0.1369	0.5558
I 23	1.5995	1.2828	0.8237	0.4659	0.1282	0.8237	0.8744	0.4084	0.1241	0.0983	0.8012
I 24	1.8365	1.5995	1.0000	0.5670	0.3401	1.0000	1.0833	0.5162	0.1613	0.1710	0.4494
J 16	2.8365	2.5564	1.7322	1.0740	0.2498	1.7322	1.8152	0.7412	0.1120	-0.2550	0.7449
J 17	2.7466	2.3219	1.5312	1.0619	0.5146	1.5312	1.6919	0.6300	0.2552	0.1578	0.7714
J 18	2.3585	1.9942	1.4779	1.0923	0.8678	1.4779	1.5433	0.4510	0.1449	0.2997	0.6529
G 16	1.5522	1.1203	0.4170	-0.4415	-0.8164	0.4170	0.3394	0.7809	-0.0993	-0.0629	0.5166
G 17	1.6038	1.2863	0.7226	0.1234	-0.3994	0.7226	0.7049	0.5814	-0.0305	-0.2071	0.7227
G 18	1.9159	1.7418	1.2379	0.8678	0.5146	1.2379	1.3048	0.4370	0.1531	-0.0517	0.6033
G 13	2.2653	1.9434	1.4150	1.0058	0.5479	1.4150	1.4746	0.4688	0.1270	-0.0179	0.8316
G 14	1.9771	1.7959	1.3292	0.9658	0.6850	1.3292	1.3808	0.4150	0.1245	0.0046	0.5566
G 3	1.9434	1.7179	1.1844	0.7809	0.4325	1.1844	1.2494	0.4685	0.1387	0.0075	0.6126
K 19	2.7959	2.2447	1.4739	1.0174	0.1219	1.4739	1.6311	0.6136	0.2560	-0.0246	1.1788
K 20	2.1976	1.7859	1.3292	0.7226	-0.4093	1.3292	1.2542	0.5316	-0.1409	-0.8182	1.4517
K 21	2.0469	1.8365	1.3884	1.0321	0.7419	1.3884	1.4343	0.4022	0.1142	0.0149	0.6225

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13. ABSTRACT

An ecological survey of a sandy beach was made to determine relationships between population densities and sand grain size distributions, season and height above the tidal datum plane (MLLW). Fifteen species of invertebrates in four phyla were collected. Four zones relative to tidal datum and two major habitats - protected outer coast sandy beach and outer coast sandy beach - were defined. Nephtys caecoides, Nephtys californiensis and Archaeomysis maculata showed distinctive distribution patterns relative to mean grain size which require further investigation.

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